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ELECTRIC INITIATORS: A REVIEW OF THE STATE OF THE ART

by

Gunther Cohn

November 1961

Prepared for

PICATINNY ARSENAL
Feltman Research and Engineering Laboratories
Artillery Ammunition
Rocket and Development Laboratory
ORDBB-DR4

TIPER A

Department of the Army Contract DA-36-034-501-ORD-3115RD
Department of the Army Project 505-01-003
Ordnance Corps Project TN1-2707

FRANKLIN INSTITUTE
LABORATORIES FOR RESEARCH AND DEVELOPMENT
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FOREWORD

The subject of electric initiators has been discussed at two technical meetings held at The Franklin Institute within a six-month period. The Electric Initiator Symposium, held in November 1960, concerned electric initiators in general and covered a review of initiator programs, exploding bridge wires, new developments and evaluation techniques. The HERO Congress, held in May 1961, concerned the hazards of electromagnetic radiation to ordnance which emphasized the aspects of the RAD-HAZ program that affect electric initiators.

Together, these two meetings represent a current survey of the state of the art in research and development on electric initiators and electroexplosive devices. All told, 65 papers were presented. The two proceedings cover over 1200 pages.

In this report we reprint the papers which summarize the two meetings. There are several reasons for doing this. First, this report now presents under one cover a summary of the latest thinking in this technical field. All papers delivered at the meeting have been concisely summarized and grouped so as to form a convenient subject index. Moreover, by issuing this summary in an unclassified form, it serves as a ready desk-top reference. The HERO Congress summary was originally unclassified. Since the Symposium summary was classified, certain portions had to be reworked. We believe however, that the necessary deletions will not detract from the usefulness of this volume.

Conducting and reporting technical meetings is one aspect of the technical documentation activity at The Franklin Institute. Related work involves review, compilation, and indexing of technical fields. One of the fields analyzed in detail has been that of initiators and electroexplosive devices. We append an annotated bibliography of a dozen basic initiator reference which we hope will increase the usefulness of this report.

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REVIEW OF ELECTRIC INITIATOR SYMPOSIUM

In November 1960 a group gathered here for an Electric Initiator Symposium. The symposium, sponsored by the U.S. Naval Ordnance Laboratory, Silver Spring, Md., was attended by 310 men from 33 Government agencies and 64 companies. It was the third such symposium, the previous ones in 1954 and 1957 being sponsored by Picatinny Arsenal, Dover, N.J. The objectives of the meeting were much like the purposes of the HERO Congress, to exchange information, to catch up on latest developments, to stimulate thinking, and to take a hard look at vexing problems. For these reasons, and since experts from all walks of research and development participated, the 30 papers delivered represent a potent state-of-the-art summary of the work on electric initiators and electroexplosive devices. This paper presents the high-lights covered at that symposium. Details are contained in the minutes which were distributed to all agencies on the invitation list and to ASTIA.

Review of Initiator Programs

The first session of the symposium included papers on a number of broad programs of related interest. The first of these is a summary of the HERO program which is, of course, the detailed subject of the HERO Congress (Paper 1, C. M. Cormack, Naval Bureau of Weapons).

A second paper described the project at the U.S. Army Engineer Research and Development Laboratories concerned with the effect of energy interactions with metastable solids (Paper 2, Dr. Z. V. Harvalik) The report includes studies on purification of specimen compounds, methods of

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crystal growth, and measurement of structural changes of compounds due to irradiation. Organization, key men, facilities, and instrumentation are described.

The third paper dealt with the Navy's program on electric initiators for power cartridges (Paper 3, S. E. Hedden and R. I. Rossbacher, Naval Weapons Lab., Dahlgren). Design requirements are related to the cartridges in which the items are to be used. Environmental conditions, production techniques, and usefulness are all factors of concern. Discussed are problems of hermetic sealing, size reduction, versatility, safety, and reliability.

Two papers from Session II also fall into this category of program review. One was by Lockheed Missiles and Space Division on initiators for space applications (Paper 5, I. B. Gluckman). In space, initiators are called on to perform over a dozen important functions. It is essential that design efforts be applied to meet the requirements of extreme temperature, thermal shock, and high vacuum. Initiators should be relatively insensitive and must be highly reliable. Typical sensitivity requirements are one-half ampere no-fire and two amperes all-fire.

Picatinny Arsenal discussed the philosophy of explosive train design (Paper 12, R. L. Wagner and P. B. Tweed). In the past, all fuzes were made detonator safe and bore safe by means of an out-of-line explosive train. Based on the results of impact tests, nothing more sensitive than RDX (Army use) or tetryl (Navy use) is permitted in-line. While an out-of-line device is complex and while details remain to be questioned, these

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rules have produced the desired level of safety. A number of development programs are now under way in the United Kingdom and on contract for Picatinny Arsenal to explore the possibility of an initiator containing no sensitive (primary) explosives. It appears that such a secondary explosive detonator is practicable. Metallic conductive mixes appear to be too sensitive mechanically for this application but graphited mixtures and other mechanisms seem to be promising. It was the purpose of the paper to present an attitude toward safety rather than to propose in-line devices. Incidentally, in another paper, Lockheed MSVD Division indicated that their instructions do not call for S&A devices on EBW items.

Exploding Bridge Wires

Five papers in Session II covered the subject of initiation by means of exploding bridge wires. One of the reasons for the great amount of interest shown in EBW's is the expectation that they will be able to initiate secondary explosives directly so that a primary explosive need not be used. The paper by Librascope Div. of General Precision Inc. dealt specifically with this subject (Paper 9, R. C. Maninger). Here, the sensitivity of the secondary explosives PETN and RDX is measured when initiated by EBW's by capacitor discharge pulses. Results are interpreted in terms of "hot spot" and shock wave initiation theories and particle size of explosives.

The other papers in this group were concerned with exploring various aspects of initiation theories. Lockheed Aircraft Corp. examined EBW's for possible use in Polaris missiles (Paper 6, J. K. Lightfoot).

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The system components investigated are (1) high voltage power source, (2) transmission line and connectors, and (3) exploding bridge wire initiators. It was found that transmission line characteristics are important, that there is a minimum desired current density, and that an epoxy coating of the bridge wire is beneficial.

U.S. Flare Div. of Atlantic Research Corp. is applying EBW's to squibs of four types (Paper 8, S. F. Mulich and H. E. Curtis): (1) air gap squib, (2) transfer charge squib, (3) barrier squib, and (4) high auto-ignition squib. Characteristic parameters are established in experimental tests and compared with those of semiconductor squibs.

Aerojet-General Corp. (Paper 10, L. Zernow, G. Woffinden and F. Wright, Jr.) observed the behavior of an electric discharge through wires and films both electrically and optically. A cinemicroscopic study of the behavior of exploding tungsten wires shows them to be strongly influenced by impurities in the wire. The explosion of thin aluminum films was found to be a two-stage process. The primary process, conduction, results in vaporization and the vaporized regions provide a secondary breakdown path.

Picatinny Arsenal discussed its programs on EBW research and development (Paper 13, M. T. Hedges). Items are being developed for both ignition and detonation outputs. Two aspects are featured in the studies: (1) new explosive materials having unique properties related to EBW

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requirements, and (2) thorough investigation of transmission line efficiency, which is critical.

Other Initiating Systems

Seven papers in Session II dealt with initiating mechanisms other than EEW's. Here again, the interest in secondary explosive detonators is evident. McCormick-Selph Assoc. studied film resistor initiators (Paper 7, R. W. Lynch and R. C. Allen). The high resistance needed in standard bridgewire initiators is presently achieved with small diameter wires which can be susceptible to accidental firing. Studies showed that when replacing the bridgewire with a film resistor, selection of resistor surface area is independent of total resistance. This step provides voltage and current insensitivity simultaneously.

A. R. D. E. of United Kingdom conducted experiments with several types of low energy detonators incorporating only secondary explosives (Paper 11, Neill Griffiths): (1) a hot wire system requiring a low voltage, high current power source, and (2) a conductive mix system operating from a high voltage power source of limited current capacity. Studies include experiments with different explosives, particle sizes, and loading pressures.

Armour Research Foundation developed a secondary explosive, low energy detonator which employs a mixture of RDX and acetylene black as initiating composition (Paper 14, J. Weber, R. H. Stresau and J. Savitt). An air gap is employed to facilitate transition from deflagration to detonation. Firing energies of 50,000 to 3,000,000 ergs are obtained in different designs.

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The direct initiation by sparks of conductive mix initiators containing only secondary explosives was discussed in two related papers, both by Naval Ordnance Laboratory, Silver Spring, Md. (Papers 15 and 16, H. Leopold, T. P. Liddiard and B. E. Drimmer). The first of these two papers deals with test vehicles and spark gap configuration while the second study is concerned chiefly with the alterations in the process due to the addition of powdered electrical conductors.

Lead and silver azide were the subject of another experimental program by Naval Ordnance Laboratory, Silver Spring, Md. (Paper 17, R. H. Stresau and M. H. Rowe). The study was designed to compare the sensitivity of the azides to hot wire initiation and their tendency to affect the transition from burning to detonation. The hot wire sensitivity, as measured by Bruceton tests, was found to increase significantly at high densities.

A paper by R. H. Stresau was not presented at the meeting but is included in the minutes (Paper 17a). It develops a theory of the growth of detonation from sources of subcritical dimensions.

New Developments

A regular feature of the symposium was the review of recent developments. Seven papers in Session III were devoted to this aspect in which eight agencies described some 40 developments. The items are summarized in Table 1. The agencies with the large number of presentations are the ones with the development mission, Picatinny Arsenal, Naval Ordnance Laboratory, Corona, Cal, Naval Ordnance Laboratory, Silver Spring, Md., and

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Table 1

NEW DEVELOPMENTS REPORTED AT ELECTRIC INITIATOR SYMPOSIUM

Item	Reported by	Paper
Ignition Compound for EBW's New Explosives (6)	Picatinny Arsenal M. T. Hedges Picatinny Arsenal D. E. Seeger	13 19I
T24El Detonator with Powdered Iron Plug Assembly	Picatinny Arsenal S. M. Adelman	19II
Attenuating Plugs for MARK 2 MOD 0 and MARK 7 MOD 0 Ignition Elements	Picatinny Arsenal	19II
Miniature Hermetically Sealed Squib Switch	Picatinny Arsenal S. J. Lowell	19IIIa
Self-Destruction Tracer System for 37 mm Ammunition	Picatinny Arsenal S. J. Lowell	19IIIb
Miniaturized Detonators T60, T61, T62, T65, and T68 (delay) and T29 (stab -electric)	Picatinny Arsenal R. H. Heinemann	19IV
High Temperature Resistant Detonators MARK 75 and MARK 76	Nav. Ord. Lab., Corona R. M. Hillyer	20
Delay Detonators MARK 73 and MARK 74	Nav. Ord. Lab., Corona	20
Five Electric Squibs Including Miniature, High-Altitude, and Delay Items	Nav. Ord. Lab., Corona Rex Smith and Jack Sherman	21
Explosive Bolts(4), Squib Actuators(2), Detonator, Driver, and Line Charge Initiator	Nav. Ord. Lab., Silver Springs V. J. Menichelli	24
Miniature Delay Switches of 0.1 and 10 Seconds Delay	Atlas Powder Co. H. Hulka B. Gay L. Edwards G. Bills Nav. Ord. Lab., White Oak G. H. Martin	26
Conductive Mix Detonator for Firing from 1.5 Volt Source (Proprietary)	Beckman Inst. Inc. Dr. D. D. Taylor P. J. Langdon	27
Detonator with Symmetrical Radial Output	Sandia Corp., Aerojet-General Corp. Howard J. Fisher	28

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Naval Ordnance Test Station. Items presented are described as being successful and no problems were raised. Major objectives were to make EED's smaller, more reliable, and safer. Two developments are discussed at length, Beckman Instruments, Inc. described a conductive mix detonator. Development concerns both conductive mix and hardware. Sandia Corp. and Aerojet-General Corp. described a detonator with symmetrical radial output. Reliability is achieved with dual bridge wires.

Evaluation

The balance of Session III contained papers on initiator characteristics, evaluation, and instrumentation. In discussing the response of EED's to transient electrical pulses, Naval Ordnance Laboratory, Silver Spring Md., views the EED as an energy transducer converting electrical input energy into heat in the explosive of the system (Paper 18, I. Kabik, L. A. Rosenthal and A. D. Solem). Making certain assumptions, basic thermal equations are derived and solutions of the mathematical model compared with experimental data for the wire-bridge MARK 1 Squib. Good agreement was obtained over wide ranges of input conditions for capacitor discharge and constant current pulses. The model makes available a means for accurately predicting the response to electrical energy in the region where thermal losses are high. The model was also used to predict the response to radar and communications equipment. Here, the temperature excursions depend on power level, repetition rate, and pulse width.

The Franklin Institute described the FILUP (Universal Pulser) which is a big brother to the FILITS (Initiator Test Set). While the standard FILITS subjects an EED to capacitor discharge pulses, the FILUP

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is the new instrument for delivering electrical pulses, either constant current or constant voltage, of accurately controlled duration and amplitude (Paper 22, C. T. Davey). Two systems of pulse control are used: (1) silicon controlled rectifiers handle currents up to 35 amperes and (2) thyratrons handle short intervals and deliver pulses up to 800 volts. The FILUP is complete in itself except for the firing chamber. It has internal calibration, digital voltmeter for ease, speed and accuracy, oscilloscope for viewing pulse wave forms or other desired events, and means of measuring the resistance of the devices under test with currents limited to values which will do no damage.

The Franklin Institute also reported three recent evaluation and calibration studies (Paper 25, R. G. Amicone): (1) The third edition of the Electric Initiator Handbook has been published. In addition to covering new initiators, the new edition contains new test data, among them being response to constant current stimuli and performance at extreme temperatures. (2) A mathematical model was developed to estimate the probability of accidental firings due to spurious currents which are both large and repetitive. The procedure, in which the resistance decay of wire bridges is measured, is expected to be useful for predicting the behavior of wire bridges in a variety of applications. (3) A device was developed to detect and indicate the presence of dangerous electrical noise in circuit locations normally occupied by EED's. This prelaunch checkout indicator is installed in place of the EED to determine whether the EED would function under the test conditions. While the unit described is

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used to ascertain the safe no-fire conditions, it is equally applicable to checking the reliable all-fire condition with small modifications in its circuitry.

From Naval Ordnance Laboratory, Silver Spring, Md., came a statistical study designed to describe the response of an EED to different levels of stimulus (Paper 29, L. D. Hampton and J. N. Ayres). Squib MARK 1 MOD 0 was used to determine the statistical model. It was concluded that the log-logistic model is better than the log-gaussian to describe the response of the MARK 1 MOD 0 squib to capacitor discharge stimuli.

Naval Ordnance Laboratory, Silver Spring, Md., also reported on the energy requirements of multiple initiators which are used in circuits to increase reliability (Paper 30, E. E. Kilmer). Tests were made with MARK 114 MOD 0 wire bridge primers and MARK 121 MOD 0 carbon bridge primers to determine how firing characteristics are changed when two devices are used, either in series or in parallel, compared to circuits calling for a single primer. In general, the energy to fire two devices was found to be more than twice as great in capacitor discharge tests than that for a single device.

Problem Areas

To summarize the symposium in another way, let us cite the four problem areas which were mentioned during the meeting:

- (1) HERO (Paper 1). As mentioned before the HERO paper is a summary of this particular problem area.

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- (2) Power cartridges (Paper 3). It was stated that future refinements are needed. There are few available electric igniters which can be recommended for Navy power cartridge application.
- (3) Space application (Paper 5). Future space needs were outlined. Tomorrow's objectives are more demanding and environments are more severe.
- (4) EEW's (Papers in Session II). Several speakers dwelled on the problems associated with exploding bridge wire initiators, dealing with reliability on one hand and safety on the other. Problem areas include in-line vs. out-of-line safety, insensitive explosives, and hot-wire sensitivity and transmission line losses.

These then are the highlights of the papers of the Electric Initiator Symposium. By covering review of initiator programs, exploding bridge wires, other initiating systems, new developments, and evaluation, the purposes of the meeting were fulfilled.

Copies of the proceedings have been distributed to all who attended. If you do not have a copy, you may obtain one from ASTIA (AD-323 117). A limited number is still available for distribution by applying to the Naval Ordnance Laboratory, Silver Spring, Md., Attn: Mr. I. Kabik.

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REVIEW OF HERO CONGRESS

The HERO Congress, on Hazards of Electromagnetic Radiation to Ordnance, was held at The Franklin Institute in May 1961. The Congress, sponsored by the U.S. Naval Weapons Laboratory, Dahlgren, Va., was attended by about 290 men from 55 Government agencies and 68 companies. The purposes of the meeting were to exchange ideas and to stimulate efforts toward early solutions to present problems. Hence, the 35 papers delivered and the discussions which followed them represent the state of the art of the HERO program. This paper summarizes the highlights covered at the Congress. Details are contained in the proceedings which are distributed to all agencies on the invitation list and to ASTIA.

Keynote

The meeting opened with welcomes by J. G. Richard Heckscher, Executive Vice President of The Franklin Institute and by Capt. M. W. Whitaker speaking for Capt. T. H. Morton, Commanding Officer of the U.S. Naval Weapons Laboratory, Dahlgren Va. The keynote address by R. Adm. F. L. Ashworth, Assistance Chief for Research, Development, Test and Evaluation of the Bureau of Naval Weapons (Paper 1) was delivered by Capt. J. E. Dacey, Director of Research and Engineering. The paper traced the advent of modern high-power transmitters and electroexplosive devices. It charged the assembly to solve any potential problems.

The Three Services

The remaining papers in the first session reviewed the efforts by the Three Services. The Air Force program is conducted in areas of

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research, development, and in-service engineering (Paper 2, Capt. T. J. Vernia, A. F. Systems Command). Research projects concern (1) biological effects on personnel and (2) determining the non-susceptibility of EED's. Development includes preparation of specifications, and engineering includes fixes.

The Army's program is designed to insure recognition of deficiencies in current weapon systems with respect to RF susceptibility (Paper 3, G. M. Rosenberg, W. G. Queen, ORDTN). The program, concerned with both hazard and reliability aspects, includes RF field intensity measurements, tests, instrumentation development, and fixes.

The Navy is the coordinator of the RAD-HAZ program (Paper 4, C. M. Cormack, Jr., BuWeps). The program dealing with RF effects on fuel and fueling (SPARKS) is under the direction of the Bureau of Ships, that dealing with personnel hazards (Bioeffects) is of primary concern of the Bureau of Medicine and Surgery, while that dealing with RF effects on ordnance (HERO) is directed by the Bureau of Weapons. Major HERO coordination effort consists of (1) determination of weapon susceptibility, (2) supporting research, and (3) fixes.

Several other papers elaborated upon work at specific installations. Possible harmful effects of RF energy on man are being studied at Rome Air Development Center (Paper 18, Col. G. M. Knauf, Patrick A.F. Base, Col. K. F. Troup, A.F. Cambridge Research Center). It was shown that man can be protected without difficulty from the production of heat in exposed living tissue.

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Picatinny Arsenal has studied the effects of shielding, filter networks, broadband RF attenuators, and insensitive systems for eight years (Paper 12.1, P. B. Tweed). Work at Naval Weapons Lab. included (Paper 20, L. S. Pruett and P. S. Altman): (1) analysis of present initiators, (2) development of new initiators immune to RF, (3) development of instrumentation, and (4) measurement of electromagnetic properties of explosives.

The following four papers are concerned primarily with plans or suggestions for the future. Hill Air Force Base plans to study safety reports of in-service items and develop safety specifications (Paper 6, H. R. Laughter). Antennas and transmitting equipment were described which will make up the future RF environment aboard ship (Paper 19, Cdr. B. D. Inman, BuShips). Power densities will be increased by significant amounts.

The Naval Weapons Evaluation Facility suggested design criteria (Paper 34, H. W. Richardson). The criteria discussed covered the susceptibility of nuclear weapons to the vulnerability environments, which are: fire, impact, fragmentation, pressure, thermal radiation, nuclear radiation, electronic countermeasures, and electromagnetic radiation. Designing RF immunity into a weapon system is difficult (Paper 35, J. S. Nichols, Naval Weapons Lab.). The universal fix is as elusive as eternal youth. Rather, we must consider the environment and apply sound engineering design practices.

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Topics of Related Interest

Several programs presented at the meeting are pertinent to the subject of the Congress. The first of these is a summary of R&D in the United Kingdom (Paper 14, R. E. Cousens, D. McIlroy and F. A. Green). The service agencies concerned with the RF problem are the Ordnance Board, A.R.D.E., R.A.E., and A.S.W.E. To date, the effort in the UK has been small compared with that of the U. S. Work has been restricted to development of equipment and test techniques for measuring pick-up in aircraft wiring and bridge initiators. UK also analyzed the effect of a lightning strike on capsules containing explosives (Paper 16, A. B. Hillan). Danger of a lightning strike can be minimized by use of good design practices, such as avoiding casing holes and multiple grounds.

Hughes Aircraft Co. reported its studies on how nuclear radiations modify the properties of electronic materials and circuits (Paper 15, T. D. Hanscome). Electrical response during radiation can produce damage to electronic equipment but large doses are needed to produce marked damage. ERDL presented data on fragmentation phenomena due to energy interactions which are correlated with initiation mechanisms of primary explosives, such as azides (Paper 13, Z. V. Harvalik). The Franklin Institute summarized the highlights of the papers presented at the Electric Initiator Symposium in November 1960 (Paper 26, Gunther Cohn).

Energy Coupling

Several papers dealt with propagation and absorption. Sandia measured the electromagnetic energy delivered to 18 electroexplosive

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devices within an ordnance system over a frequency range of 200 kc to 10 Gc (Paper 7, G. W. Rodgers). The data reveal many of the relationships among the various coupling possibilities. Jansky and Bailey, Inc. predicted the current or voltage received by an EED from an electromagnetic radiator near an ordnance device (Paper 10, W. T. Dickinson). The two situations considered are (1) the near-field case, as aboard ship and (2) the far-field case, frequently found at shore installations. P. D. Crout, consultant for NOTS, described three mathematical tools which can be applied to antenna and boundary value problems (Paper 11). The tools are (1) integral equation, (2) method of virtual displacement, and (3) method of successive adjustments.

Present trends in the design of transmitters, receivers, and antennas were reviewed by the University of Pennsylvania to assess their impact on interference, interference measurement techniques, shielding, and prediction methods (Paper 17, O. M. Salati). It was shown that field intensity meters, filters, and tunable preselectors must be improved for optimum future work.

The existence of two modes of RF excitation in two-wire shielded systems was discussed by Naval Weapons Lab. (Paper 21, Wg. Comdr. R. Gray). The first is the differential or Lecher mode while the second is the coaxial mode. The latter may cause spurious initiation at energy levels lower than those required for normal initiation and may also create errors in instrumentation.

A paper by Holey, Inc. discussed the relationships between bridge-wire resistance, no-fire current, and initiation energy requirements

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and the total susceptibility to initiation from induced emf (Paper 29, E. J. Stecker). A proposed analytical method establishes the least susceptible design.

Data on Specific Devices

White Sands reported on tests performed on the Nike-Hercules system during the summer of 1960 (Paper 8, G. E. Galos, H. Cutcher). Results of squib measurements were compared with those from antenna theory.

The M990 electric bomb fuze is the subject of two papers. The first described results of newly developed evaluation test methods at Naval Weapons Lab. (Paper 9, R. R. Potter). The second paper suggested a fix for the fuze (Paper 22, D. E. Allmand, NOL). The fuze system was found to be susceptible to inadvertent actuation by RF energy. The fix consists of two parts, an RF switch at the bomb-aircraft interface and mechanical locks within the fuze.

Picatinny Arsenal described its work on RF protected initiators by means of powdered iron attenuating materials (Paper 12.2, S. M. Adelman). This solution has been applied to the T24E1 wire-bridge detonator and to the MARK 2 and MARK 7 ignition elements. Several other detonators will be similarly equipped. Picatinny is also investigating the approach of achieving RF protection by means of high-energy electric initiators that can be used in "in-line" because they are mechanically insensitive (Paper 12.4, R. L. Wagner).

The potentialities of various high-dielectric constant capacitors to protect electroexplosive matches were investigated by American Machine

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and Foundry Co. (Paper 24, L. F. Dytrt). Reasonably high degrees of protection are realized in the frequency range 0.25 to 50 Mc.

Wire Bridge Initiators and EEW's

Two papers discuss the following aspects of wire bridges in relation to RF. In its study, Naval Ordnance Lab., White Oak, viewed the EED as an energy transducer (Paper 32, I. Kabik, J. N. Ayres and A. D. Solem). Solution of the thermal equations were compared with RF tests of the MARK 1 squib. Naval Weapons Lab. derived relationships between bridge wire dimensions on one hand and threshold pulse energy and mean power on the other (Paper 33, Wg. Cdr. R. L. Gray). Design parameters of an initiator family can be based on measurements of a prototype.

Exploding bridge wires and their behavior were the most discussed topic at the meeting. First, Picatinny Arsenal described the EEW (Paper 12.3, M. T. Hedges). EEW's are characterized as safe and reliable items requiring high-energy input. Next, Librascope presented a trigger circuit design (Paper 23, M. L. Loyd). Trigger discrimination methods were discussed to achieve any desired safety level.

Finally, The Franklin Institute summarized the status of the art of EEW's as related to RF (Paper 25, P. F. Mohrbach). EEW's were defined. They are often characterized as having high functioning reliability and containing only secondary explosives. Unfortunately, little data exists on EEW's in actual weapons so that the need for significant data is great. Discussion included a variety of answers to

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the following questions: (1) Precisely how is an EBW defined as distinguished from an insensitive initiator?, (2) Will the special firing systems used for the EBW's work just as well on ordinary EED's?, and (3) Can EBW's be fired by RF?

Instrumentation

Four installations described the instrumentation at their test facilities. Naval Weapons Lab. presented its detecting and recording instrumentation for simulating RF environments on the ground plane and in the laboratory (Paper 5, C. L. Hinkle). The paper included the significance of test results. Sandia recently completed a test facility to measure the power received by various EED's when an ordnance system is exposed to electromagnetic fields (Paper 27, R. L. Parker). The system uses low radiated power and sensitive detector.

Denver Research Institute is investigating sensors which indicate the degree of bridge wire heating due to RF energy (Paper 30, R. B. Feagin, and J. G. Hewitt). Thermocouples, thermistors, and photoconductors have been used to measure the small temperature rises. Instrumentation at The Franklin Institute is designed to determine RF sensitivity of EED's and to evaluate attenuation materials (Paper 31, P. F. Mohrbach and R. F. Wood).

Problem Areas

To summarize the congress in another way, let us look at the problem areas mentioned in the meeting. Each of the problems was mentioned in several papers:

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- (1) RF Specifications - We need specifications for test, design, and manufacture. Formulation of such specs. requires further study because present data are judged to be inadequate for this purpose. In this connection, we also need better specs. on environments.
- (2) EEW's - We need a better understanding of all factors in the EEW area. More tests must be made to yield significant and well defined data. We need facts.
- (3) Transducer components - To permit meaningful measurements of RF effects, we need better dissipative filters for transmitters, more versatile sensitive broad band equipment for measuring field strength, and improved highly selective tunable preselectors.
- (4) Detectors - We need simulators or detectors, or where they exist, we need better, more sensitive, and faster responding devices. Examples are carbon bridge simulators, vacuum thermocouples of faster response, and simulators which will behave like EED's as far as thermal and electrical characteristics are concerned.

It is not within the scope of this summary to rate the presentations. Many of the papers were excellent. The following two papers are singled out, however, as being most helpful for future efforts:

- (1) Paper 35 which dwells on the philosophy of guarding against RF susceptibility and (2) Paper 34 which stated concisely the elements that constitute sound design.

These, then, are the highlights of the HERO Congress. The papers presented did much to help solve potential problems.

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INITIATOR BIBLIOGRAPHY

Recommended by Gunther Cohn

Here are a dozen basic initiator references that should be on the bookshelf of all workers in the field. We wrote half of them ourselves: documentation is our business. Compiled and annotated October 1960, revised May 1961.

1. General Information

"Ordnance Explosive Train Designer's Handbook," Naval Ordnance Laboratory, White Oak, Report NOLR 1111, April 1952, Confidential.

This handbook brings together in concise form the principles in the art and the science of explosive train design. The only text on this subject, at is the major source of reference. There are covered in detail the characteristics of each explosive component in the train, the interaction of these components, the measurement techniques and the considerations of loading. References are appended to each chapter and there is a glossary of terms. (Out of print. Try ASTIA).

"Statistical Methods in Initiator Evaluation," by Carl Hammer, The Franklin Institute, Interim Report I-B1804-1, Prepared for Picatinny Arsenal, ORDBB-TP3, Contract DAI-36-034-501-ORD(P)-38, May 1955, Confidential (AD-78 254).

The statistical methods contained and illustrated in this report were developed as tools to be used in describing an initiator's performance. Among the topics covered are experimental design and acceptance sampling. Hence, there is in one volume a wealth of information on the statistical procedures for the input evaluation of electric initiators. Two characteristics are considered, functioning time, a continuous variable, and sensitivity, a quantal response (fire or fail) variable.

"Electric Initiator Symposium," September 11-12, 1957 sponsored by Picatinny Arsenal and The Franklin Institute, Confidential (AD-153 579).

These proceedings contain the 35 papers presented at the Second Electric Initiator Symposium. Included also are general remarks and the discussion that followed each paper. Material is arranged into four areas: New Development, Special Considerations, Electrical Design, and Explosive Design.

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"Fuzes, General and Mechanical," Ordnance Corps
Pamphlet ORDP-20-210, January 1960.

This text was prepared by The Franklin Institute as a portion of the Ammunition Series of Ordnance Engineering Design Handbooks. An introduction outlines purpose and general functioning of fuzes. Part One goes thoroughly into functioning actions including explosive trains while Part Two discusses basic arming actions. Part Three treats the overall design of fuzes for all classes of application. Glossary, references, index.

"Cook-off in Aircraft Guns Summary," 1952-1959, Gunther Cohn,
The Franklin Institute, Contract DA-36-034-501-ORD-10RD, June
1960 (AD-239 808).

This report summarizes the studies of cook-off in aircraft guns. Covered are theory of cook-off (self-ignition of explosives and propellants due to the heat of the gun), factors affecting cook-off, methods of producing it and means for prevention. Emphasis is on revolver type and Gatling type 20mm automatic weapons. Of particular interest to initiator and fuze designers are data on detonator cook-off characteristics.

2. Explosives and Initiating Compositions

"Military Pyrotechnics," Dept. of the Army Technical Manual
TM9-1981, January 1951.

Description, use, operating instructions, safe handling, and destruction procedures are given for military pyrotechnics of all types. Included is a 14-page table of data on specific items.

"Military Explosives," Department of the Army Technical
Manual TM9-1910, April 1955.

This is a comprehensive manual on explosives and propellants. It is a useful reference as a basic source of general and technical information on military explosives. Among the subjects covered are descriptions, properties, tests, handling methods, theory, and use.

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"Properties of Explosives of Military Interest," Ordnance Corps. Pamphlets, Section 1, ORDP 20-177 (U), and Section 2, ORDP 20-178 (Confidential), May 1960.

These reports contain data-sheets on over 100 explosive compounds and mixtures. Tabulated data reflect the results of tests which measure sensitivity to friction, impact, heat initiation; performance characteristics of effectiveness in weapons; and physical and chemical properties of the explosive. A method of preparation, synthesis, or manufacture is included for each type of explosive.

"Initiators and Initiating Compositions: A Literature Survey," by Alfred M. Anzalone, Picatinny Arsenal, Feltman Research Labs Technical Report 14, September 1960 Secret (Vol. I, AD-244 064; Vol. II, AD-319 506; Vol. III, AD-244 065).

This literature search resulted in the compilation of almost 1000 abstracts on initiators and initiating compositions. Included are reports by Picatinny Arsenal, its contractors, OSRD and other reports distributed to Picatinny. Subject coverage is broad; there are excluded only artillery primers, igniters, and fuzes. Volumes I (U) and II (S) contain abstracts and Volume III (U) is a coordinate index.

3. Initiator Data

"Compilation of Data on Army, Navy and Commercial Standard Electric Squibs," by Robert E. Betts, Redstone Arsenal, Report 3J14N1, January 1956.

This compilation of electric squibs is the second revision of these data. Listed are 32 Army, Navy, and selected commercial squibs. The volume is similar in nature to the Electric Initiator Handbook (Franklin Institute), and lists specifications and test data on input, physical and explosive properties.

"Army, Navy, and Air Force Fuze Catalog," by Gunther Cohn, The Franklin Institute, Report F-A2238, Contract DA-36-034-501-ORD-2802RD, March 1959, Confidential (AD-305 024). First Supplement, Report F-A2238-1, November 1959 (AD-313 702).

This volume is a reprint in report form of the Army, Navy, Air Force Fuze Catalog. The Catalog is a complete store of military and technical information of all fuzes and explosive components, both standard and developmental. Covered are 643 fuzes and 292 explosive components. Three indices locate key data.

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"Electric Initiator Handbook," Third Edition by The Franklin Institute, prepared for Picatinny Arsenal, ORDBB-DR4, Contract DA-36-034-501-ORD-3115RD, April 29, 1960, Confidential (AD 319 980.)

This handbook, recently revised, contains basic data to characterize the performance of 25 electric detonators, primers, and squibs. In addition to a data sheet for each initiator, there are curves that describe functioning time and input sensitivity for various stimuli. The methods and the equipment used (standard test set, the FILTS) are described in detail. The handbook, by defining performance characteristics, is a valuable reference for fuze designers. It is meant to serve the initiator field as the RCA tube handbook serves the electronic industry.

Helpful Addresses

For ASTIA documents:

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Armed Forces Technical
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Arlington Hall Station
Arlington 12, Virginia

For ORDP Pamphlets:

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Box CM, Duke Station
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